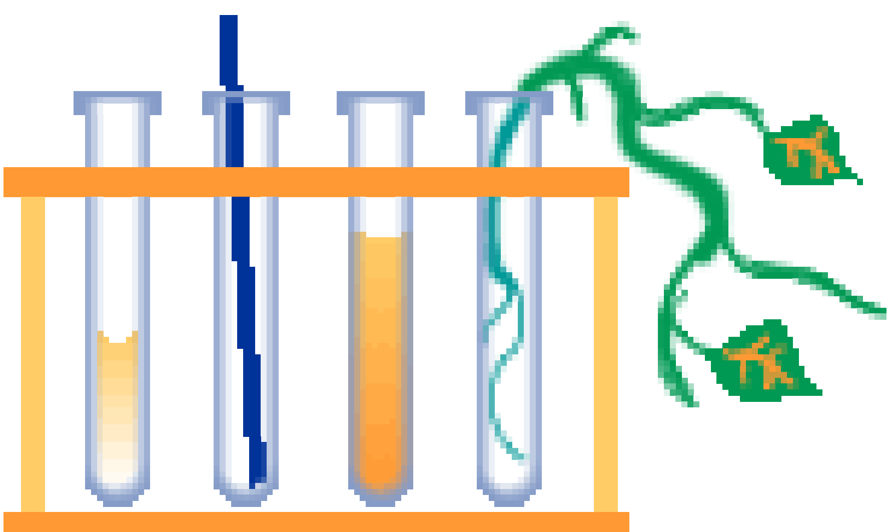
Approved by Curriculum Commission November 15, 2001 and forwarded to State Board of Education on December 14 for information and public hearing on January 9, 2002.

Draft Science Framework



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(Reviewed by SBE 1/9/02)
This version of Chapter 1 was reviewed by the State Board on January 9 and is posted here for public comment prior to the Board's final action on the Draft Science Framework.

Chapter 1 - Introduction to the Framework

The Science Framework for California Public Schools is the blueprint for reform of science curriculum, instruction, professional preparation and development, and instructional materials in this state. It outlines the implementation of the *Science Content Standards for California Public Schools* (adopted by the State Board of Education in 1998) and connects the learning of science with the fundamental skills of reading, writing, and mathematics. The Science Content Standards are a concise description of what to teach at specific grade levels, and this framework extends those guidelines by providing the scientific background and the classroom context.

Glenn T. Seaborg, one of the great scientific minds of our time, wrote in his essay *A Letter to a Young Scientist* :

> *"Science is an organized body of knowledge and a method of proceeding to an extension of this knowledge by hypothesis and experiment."*[1]

This Framework is intended to organize the body of knowledge that students need to learn during their elementary and secondary education, and to illuminate the methods of science that will be used to extend that knowledge during the students' lifetimes.

While the world will certainly change in the new century, and in ways that we can scarcely begin to predict, California's students will be prepared to meet new challenges if they have received a sound, basic education. This framework outlines the foundation of science content knowledge students need to have, and the analytical skills that will enable them to advance that knowledge and absorb new discoveries.

Audiences for the Framework

The primary audiences for this framework are the teachers and other educators who are responsible for implementing the *Science Content Standards*. These include elementary and middle school teachers with multiple subject credentials, middle and high school teachers with single subject credentials in science, and those who may be teaching outside of their primary area of expertise. The framework is designed to provide valuable insights to both novice and expert science teachers.

Designers of science instructional materials will use this framework as a guide to the *Science Content Standards*, and as an example of the scholarly treatment of science that is expected to show in their work. Publishers submitting materials for adoption in the State of California are held to a set of rigorous criteria described in this framework. These include careful alignment with and comprehensive coverage of the *Science Content Standards*, good program organization and provisions for assessment, universal access for students with special needs, and instructional planning and support for the teacher.

[1] *Gifted Young in Science: Potential Through Performance.* Edited by Paul Brandwein and others. Arlington, VA.: National Science Teachers Association, 1989. The late Dr. Seaborg was Chair of the California Academic Content Standards Science Committee that created the *Science Content Standards for California Public Schools*.

The organizers of programs of pre-service professional preparation and in-service professional development alike will find this framework helpful in their efforts.. A high degree of skill is needed to teach science well, and training programs for teachers need to be especially mindful of the expectations placed on students.

Scientists and other professionals in the community often seek ways to help improve their local schools, and they will find this framework helpful in focusing their efforts on a common set of curricular goals. By providing ideas and resources to the classroom teacher that are aligned with grade-level standards, the outreach efforts and donations from these generous individuals will be put to best use.

For many high school seniors, commencement is followed shortly thereafter by baccalaureate courses. This framework communicates to the science faculty at all California institutions of higher education, what they may expect of entering students.

Finally, the parents, guardians, and other caregivers of students will find this framework useful, as they seek to help children with homework, or understand themselves what their children are learning in school.

Instructional Materials

One of the best corrective measures that districts can take is to ensure that all teachers are provided with instructional materials currently adopted by the State Board of Education, particularly in science, mathematics, and reading-language arts. These materials are subjected to a rigorous process of review, and provide teachers and other instructional staff with guidance and instructional strategies for helping students having difficulty An analogy used in the Reading-Language Arts Framework for California Public Schools is equally applicable to the teaching of science: Teachers should not be expected to be the composers of the music, as well as the conductors of the orchestra. In addition to solid, basic instructional materials, teachers need to be able to gain access to up-to-date resources in the school library-media center that support the teaching of standards-based science. These resources must be carefully selected to support and enhance what is provided in the basic instructional materials.

The Challenges in Science Education

Long-term planning.

Elementary school students often learn much from observing and recording the growth of plants from seeds in the classroom, but the same students will not be well-served if seed planting is a focus of the science curriculum in the next year, and the next, and the following one as well. The same might be said of any instructional activity. When teachers are left to design or adopt curricular units on their own, and their decisions are not informed by grade-level specific standards, the students they teach may fail to learn new things and develop new skills. Even with good planning at the local level, students moving from district to district several times may encounter a patchwork of curricula that collectively are redundant in some areas and incomplete in others.

The *Science Content Standards for California Public Schools*, and this framework, are designed to ensure that all students have a rich experience in science in every grade, and that curriculum decisions are not made haphazardly. Curricular programs should incorporate the content standards at their respective grade levels, and be comprehensive and coherent over a span of grades.

Reforming science curriculum, instruction, and instructional materials will be a time consuming process. To achieve the reform objectives, all educational stakeholders need to adhere to the guidance provided in this framework. It may be hoped that in the near future, teachers will be able to watch students file into the classroom at the beginning of a school year, and have a much greater degree of certainty about the knowledge and skills the students already possess. Less of the valuable instructional time will be spent on review, and teachers will also have a clear idea of the content their students are expected to master at each grade level and in each branch of science.

Meeting the curricular demands from other core content areas.

The Reading-Language Arts and Mathematics Frameworks are explicit in their demands for uninterrupted instructional time in these subjects. In the early elementary grades, students need to receive at least150 minutes of reading-language arts instruction daily, and 50-60 minutes of mathematics instruction. That leaves the question of how, or even whether science instruction can be fit into the overall curriculum.

At the elementary school level, the pressure to raise the academic performance of students in reading-language arts and mathematics has led some administrators to cancel or curtail science instruction. This is not necessary and reflects, in fact, a failure to serve the students. This framework helps to organize and focus elementary science instruction, bringing it to a level of efficiency that it need not be eliminated.

All teachers, and particularly those with multiple subjects to teach, need to make judicious use of their instructional time. One of the key objectives set forth in the Mathematics Framework could apply equally well to the study of science: During the great majority of allocated time, students are active participants in the instruction. *Active* means in this case, that students are engaged in thinking about science or doing science. If an activity is paced too fast or too slow, students will not be "on task" for much of the allotted time.

When large blocks of time for science instruction are not feasible, teachers must make use of smaller blocks. These may be planned or may appear at unpredictable times. Given a block of time as brief as 5 or 10 minutes, an elementary teacher and class could have a spirited discussion on why plant seeds have different shapes, or why the moon looks different each week. Whether at a planned time or on an unexpected occasion, the teacher needs to have prepared in advance so that the discussion is well-paced, purposeful, and addresses one or more of the grade-level standards.

Science content is appropriately a part of reading-language arts and mathematics instruction. In the 2002 Reading-Language Arts and English Language Development adoption, for example, publishers were given the following mandate:

> *In order to protect language arts instructional time, those K-3 content standards in history-social science and science that lend themselves to instruction during the language*

arts time period are addressed within the language arts materials, particularly in the selection of expository texts that are read to students, or that students read.

There is no begrudging of the extended time needed for students to master reading, writing, and mathematics, for these are fundamental skills necessary for science. The Reading-Language Arts Framework states this principle clearly: *Literacy is the key to becoming an independent learner in all the other disciplines.* The Mathematics Framework bears a similar message: *The [mathematics] standards focus on essential content for all students and prepare students for the study of advanced mathematics, science and technical careers, and postsecondary study in all content areas.*

Notwithstanding the aforementioned curricular demands, it is imperative that the science standards be taught comprehensively during the elementary grades. This is a challenge that can be met with careful planning and implementation.

Setting clear instructional objectives.

In teaching the content of the Science Standards, districts must have a clear idea of their instructional objectives. Science education is meant to teach, in part, the specific knowledge and skills that will allow students to become literate adults. As John Stuart Mill wrote in 1867:

> *It is surely no small part of education to put us in intelligent possession of the most important and most universally interesting facts of the universe, so that the world which surrounds us may not be a sealed book to us, uninteresting because unintelligible.*[2]

Science education is more than the learning of interesting facts, however. It is the building of intellectual strength in a more general sense. As Arthur Bestor wrote in 1953:

> *The scholarly and scientific disciplines won their primacy in traditional programs of education because they represent the most effective methods which men have been able to devise, through millennia of sustained effort, for liberating and organizing the powers of the human mind.*[3]

Science education in grades K-12 must not be limited to the lasting facts and skills that can be remembered into adulthood, for that would be a short list indeed. Science must be taught at a level of rigor and depth that goes well beyond what a typical adult knows. The study of science disciplines the minds of students, and the benefits of this intellectual training are realized long after schooling, when the details of the science may be forgotten.

Modeling scientific attitudes

Science must be taught in a way that is both scholarly and engaging. That is, an appropriate balance must be maintained between the "fun" and "serious" sides of science. A

[2] Inaugural Address to the University of St. Andrew, quoted in DeBoer, George E. A History of Ideas in Science Education. Teachers College Press, 1991, New York. p. 8
[3] Bestor, Arthur E. *Educational Wastelands*. University of Illinois Press 1953. p. 18.

physics teacher might have students build paper airplanes to illustrate the relationship between lift and drag in airflow, but if the activity is not deeply rooted in the content of physics, then the fun of launching paper airplanes displaces the intended lesson. The fun of science can help students remember important ideas, but it cannot substitute for effective instruction and sustained student effort.

There are certain attitudes about science and scientists that a teacher must foster in students. Scientists are deeply knowledgeable about their fields of study, but typically are willing to admit that there is a great deal they do not know. In particular, they are not dismissive of new ideas that can be supported by evidence. In their research, good scientists do not attempt to prove that their own hypotheses are correct, but rather that they are incorrect.[4] Though somewhat counterintuitive, it is the surest path to finding the truth.

Classroom teachers should always provide rational explanations for phenomena, and never invoke occult or magical ones. They should be honest about what they do not know, and be enthusiastic about learning new things along with their students. They must convey to students the idea that there is much to learn, and that phenomena that are not currently understood may be understood in the future. Knowledge in science is cumulative, passed from generation to generation, and refined at every step.

Providing balanced instruction

Some of the knowledge of science is best learned by having students read about the subject, or hear it from the teacher, and other knowledge is best learned in laboratory or field studies. Direct instruction and investigative activities should be mutually supportive and synergistic. Instructional materials need to provide teachers with a variety of options for implementation that are based upon the Science Content Standards.

For example, students might learn about Ohm's Law, one of the guiding principles of physics that states that current decreases proportionately as resistance increases in an electrical circuit, operating under a condition of constant voltage. In practice, it explains why a flashlight with corroded electrical contacts does not give a bright beam, even with fresh batteries. It is a simple relationship, expressed as $V=IR$, and embodied in the high school physics standard 5b. In a laboratory exercise, students may obtain results that seem to disprove the linear relationship, however, because the resistance of a circuit element varies with temperature. The temperature of the components gradually increases as repeated tests are performed, and the data become skewed.

In this example, it was not Ohm's Law that was wrong, but an assumption about the stability of the experimental apparatus. This can be proven by additional experimentation and provides an extraordinary opportunity for students to learn about the scientific method.

Had the students been left to uncover the relationship between current and resistance on their own, their skewed data would not have easily led them to discover Ohm's law. A sensible balance of direct instruction and investigation, and a focus on demonstration of scientific principles provides the best science lesson.

Ensuring that instructional activities are safe

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[4] Platt, J.R. (1964). Strong Inference. *Science*, 146, 347-353.

Einstein's study in Princeton, NJ, shown shortly after his death. (Photo: Ralph Morse)

Safety is always a first consideration in the design of demonstrations, hands -on activities, laboratories, and science projects, on site or away from school. Teachers should be familiar with the Science Safety Handbook for California Public Schools (1999). It contains specific and useful information relevant to classroom teachers of science. Observing and promoting safe practices is a legal and moral obligation for administrators, teachers, parents, and students. Safety should be taught. Scientists and engineers in universities and industries are required to follow strict environmental healthy and safety regulations. Knowing and following safe practices in science is part of understanding the nature of science and scientific procedures.

Matching instructional activities with standards

It is important that teachers use instructional materials that are aligned with the California Science Content Standards, but how do they know when a curriculum or supplemental material is a good match? The California State Board of Education establishes scientific content review panels to analyze instructional materials submitted for adoption in grades K-8, and these panels consist of professional scientists and expert teachers of science. Districts would be well advised to use materials that have passed this stringent test for quality and alignment. The criteria are included in the framework, and may help guide the thinking of districts and schools on the adoption of grade 9-12 materials.

In brief, teachers should use instructional activities or readings that are grounded in the content of science, and provide a clear and non-superficial lesson. The content must be scientifically accurate, and the breadth and depth of the California Science Standards need to be addressed. Initial teaching sequences must communicate with the learner in the most straightforward way possible, and expanded teaching used to amplify the students' understanding.[5] The set of concrete examples, investigative activities, and vocabulary used in instruction should be unambiguous, and chosen to demonstrate the wide range of variation upon which the scientific concept can be generalized.

For example, one Grade 4 science standard is: *Students know plants are the primary source of matter and energy entering most food chains.* This should be taught using numerous concrete examples of biomes. Mastery of the concept, however, requires that students understand how the concept is generalized. Having learned by explicit instruction that plants are primary producers in deserts, forests, and grasslands, the students must be able to accurately generalize the principle to include other habitats such as salt marshes, lakes, and tundra. While the standard is easily amenable to laboratory and field activities, the entire lesson cannot be absorbed implicitly by observation or contact with nature.

In high school, the details of this standard are expanded to considerable depth, as students come to learn about energy, matter, photosynthesis, and the cycling of organic matter in an ecosystem. The grade 4 standard prepares students to learn more, and there are many examples in the Science Content Standards of this type of "pre-teaching". For example, having students learn in Grade 3 that "*all matter is made of small particles called atoms, too small to see with the naked eye*" does not make them atomic scientists. It introduces them to a way of thinking that is reinforced in Grades 5 and 8, and then taught to much greater depth in high school.

[5] Engelmann, Siegfried and Douglas Carnine. *Theory of Instruction: Principles and Applications.* ADI Press, Eugene OR, 1991

This framework is designed to ensure that instructional materials are developed to the intended depth of each standard, and the relationships among standards that grade levels and branches of science.

Science and the Environment

Environmental problems which once received relatively little attention - invasive species of plants and animals, habitat fragmentation, and the loss of biodiversity - have suddenly become statewide priorities. Entire fields of scientific inquiry such as conservation biology, landscape ecology, and ethnoecology have arisen to address these new concerns. Overall, there is an increased sense of the complexity and interconnectedness of environmental issues. The public response to California's changing environment has been profound as evidenced by the passage of Senate Bill 373 (2001).

The California Education Code is clear about our "obligation to understand the world" in which we live, so that we may make the "highest use of the land and resources" we hold in trust for future generations (Ch. 4, Sect. 8704). Environmental education projects are replacing asphalt school grounds with gardens, recycling school waste projects, contributing scientific data to international web sites, and restoring local habitats. The incorporation of environmental education provides the scientific and critical thinking skills so that students have the ability to perceive patterns and processes of nature, the skills necessary to research environmental issues, and to propose reasoned solutions.

The science content standards are strongly linked to topics and activities pertaining to environmental education. Students in grades K-5 learn about the characteristics of their environment through their studies of earth, life and physical sciences. For example, at Grade 3 students learn about how environmental changes affect living organisms. Although at Grade 6-8 Sixth grade students focus on earth, life and physical science there are still topics related to ecology and the environment found at each grade level. Students in grades 9-12 expand their knowledge of habitats, biodiversity, and ecosystems associated with the biology/life science standards. High school earth science standards include the study of energy and its usage, as well as topics related to water resources and the geology of California. In short, the issues of the environment and ecology are embedded in the science content standards.

Environmental education is not advocacy for certain opinions or interests, but a means of fostering a comprehensive and critical approach to issues, enhancing a personal sense of responsibility among students for the environment, and tying schools more closely to the life of their communities.

Guiding Principles of Effective Science Programs

The following principles direct the purpose, design, delivery, and evaluation of science instruction in an effective science education program. They address the complexity of the science content, and the methods by which science content is best taught.

Effective science programs:

- ***Are standards-based and utilize standards-based instructional materials.***

Comprehensive, standards-based programs are those in which curriculum, instruction, and assessments are aligned with the *Science Content Standards* at all grade levels (K-8) and in content strands (9-12). Students have opportunities to learn foundational skills and knowledge in the elementary and middle grades and to understand concepts, principles, and theories at the high school level. Students use instructional materials that are adopted by the State Board of Education (K-8) and are closely aligned with the *Science Content Standards* (K-12).

- ***Develop students' command of the academic language of science used in the content standards.***

Lessons explicitly teach scientific terms as they are presented in the content standards. New words (e.g., *photosynthesis*) are introduced to reflect students' expanding knowledge, and the definitions of common words (e.g., *table*) are expanded to incorporate specific meanings in science. Developing students' command of the academic language of science must be part of instruction at all grades (K-8) and in the four content strands (9-12). Scientific vocabulary is important in building conceptual understanding, and teachers need to provide explanations of new terms and idioms using words and examples that are clear and precise.

- ***Reflect a balanced, comprehensive approach that includes the teaching of investigation and experimentation skills along with direct instruction and reading.***

A balanced, comprehensive approach to science includes the teaching of investigation and experimentation skills along with direct instruction and reading. The investigation and experimentation standards are progressive and need to be taught in a manner integral to physical, life, and earth science content as students build a working understanding of scientific inquiry. For example, the metric system is first introduced in the second grade, but students use and refine their skill in metric measurement through to high school. The methods and skills of scientific inquiry are learned in the context of the key concepts, principles, and theories set forth in the standards. Effective use of limited instructional time is always a major consideration in the design of lessons and courses. Laboratory space and materials, library access and resources are essential to support students' academic growth in science.

- ***Use multiple instructional strategies and provide students multiple opportunities to master the content standards.***

Multiple instructional strategies, including direct instruction, teacher modeling and demonstration, and investigation and experimentation, are useful in teaching science and need to be included in instructional materials. Instruction is designed and sequenced to provide students opportunities to reinforce foundational skills and knowledge and to revisit concepts, principles, and theories previously taught. In this way, student progress is appropriately monitored.

- ***Assess students' knowledge and understanding on a continuing basis and make appropriate adjustments during the academic year.***

Effective assessment (on a continuing basis through the academic year) is a key ingredient of standards-based instruction. Teachers assess students' prerequisite knowledge, monitor student progress, and evaluate the degree of mastery of the content called for in the standards. Lessons include embedded unit assessments that provide formative and summative assessments of student progress. Teachers and administrators regularly collaborate to improve science progress by examining the results of California Standards Tests in science.

- ***Engage all students in learning and prepare and motivate students for further instruction in science.***

Students who need special assistance to achieve grade-level expectations are identified early and receive support. Students who are unable to keep up with the expectations for learning science often lack basic skills in reading comprehension and mathematics. For these students, schools will want to use transitional materials that accelerate the students' reading and mathematics achievement to grade level. Advanced learners must not be held back, but rather be encouraged to study science content in greater depth.

- ***Utilize technology to teach and assess content knowledge, develop information resources, and enhance computer literacy.***

The increasing use of technology is a hallmark of science today. Across the nation, science in the laboratory setting involves specialized probes, instruments, materials, and computers. Scientists extend their ability to observe, analyze data, study the scientific literature, and communicate through the use of technology. Computers are a seamless part of scientific data acquisition and analysis as well as scientific literature review. High performance computing capabilities are used in science to make predictions based on fundamental principles and laws. Technology-based models are used to design and guide experiments, making it possible to eliminate some experiments and to suggest other experiments that previously might not have been considered. Scientific advances are communicated in all forms of electronic media. Students have the opportunity to use technology and model the way modern science is done. Teaching science using technology is important for preparing students simultaneously to be scientifically and technologically literate.

- ***Have adequate instructional resources as well as library-media and administrative support.***

Standards-based teaching and learning in science demands adequate instructional resources. LEAs and individual school sites need to include science resources as an integral part of the budget. Library-media staff must have science as a priority for resource acquisition and development. Administrators must ensure that funds set aside for the science resources are spent efficiently (e.g., through clear processes and procedures for purchasing and maintenance) and support students' mastery of the content standards. This requires planning, coordination, and dedication of space for the science resources.

- ***Utilize standards-based connections with other core subjects to reinforce science teaching and learning.***

In self-contained classrooms, teachers incorporate science content in reading, writing, and mathematics in keeping with the *Reading-Language Arts* and *Mathematics Frameworks*. In departmentalized settings (middle and high school levels), science teachers need to include essay assignments and require that students' writing reflect the correct application of English-language conventions, including spelling and grammar.

Organization of the Framework

This framework is primarily organized around the *Science Content Standards for California Public Schools* (California Department of Education 2000). The framework:

- Discusses the nature of science and technology, and the methods by which they are advanced (Chapter 2).
- Describes the curriculum content and instructional practices needed for mastery of the standards. (Chapter 3).
- Guides the development of appropriate assessment tools (Chapter 4).
- Suggests specific strategies to promote access to the curriculum for students with special needs (Chapter 5)
- Describes the system of teacher professional development that should be in place for effective implementation of the standards (Chapter 6)
- Specifies the requirements for instructional resources, including investigative activities (Chapter 7).

The California *Science Content Standards* are embedded in Chapter 3, and are grade-level specific from Kindergarten through Grade 8. The standards for Grades 9-12 are organized into the content areas of Physics, Chemistry, Biology, and Earth Sciences. Standards for Investigation and Experimentation are included at each grade level, and are different from the others in that they do not represent a specific content area. Investigative skills cut across all content areas, and these standards are intended to be taught in the context of the grade level content, and to consume 25% (or less) of the science instructional time in grades K-8.

Chapter 2 - The Nature of Science and Technology

Science is the study of nature at all levels, from the infinite to the infinitesimal. It is the asking and answering of questions about natural processes or phenomena that can be directly observed or indirectly inferred. From this process come tentative explanations called hypotheses, which lead to testable predictions about such phenomena. Hypotheses that successfully stand up to rigorous testing of predictions will, over time, lead to an accumulation of facts and principles that serve as the foundation of scientific theories. From out of this well of scientific knowledge are drawn the technologies that drive a society's economy and lift the quality of life for its people.

Scientific knowledge and technology built on that knowledge have expanded, one might even say exploded, in the last 50 years. It is the very nature of science as a human endeavor that has made this expansion possible. Scientific research and development are both collaborative and international, with literally millions of men and women around the world participating in the science and engineering enterprise.

To stay current with scientific developments, school science programs need to develop partnerships with library media centers, museums, science and technology centers, colleges and universities, industry and/or subject matter projects in order to build support for science programs.

The Scientific Method

The scientific method is a process for predicting, based on a handful of scientific principles, what will happen next in a natural sequence of events. Because of its success, this invention of the human mind is used in many fields of study. It is a flexible, highly creative process built upon three broad assumptions: (1) Change occurs in observable patterns that can be extended by logic to predict what will happen next; (2) Anyone can observe and apply logic; (3) Scientific discoveries are replicable..

The first assumption may be contrasted with the idea that the complexity of Nature is so great as to be outside of human understanding. Science asserts that change occurs in patterns within our capability to perceive, that these patterns may be discerned by observation, and that the changes are subject to logic. The simple logic of if-A-then-B suffices to understand simple patterns; complex patterns require the more complex logic expressed in mathematics. The concentration of thought that mathematics lends to the study of the natural world is stunning. For example, the position of the planets over the past 4 billion years can be determined using only two strings of symbols taken from Newton's laws of motion and gravity.

$$F=ma \text{ and } F=Gm_1m_2/d^2$$

The second assumption holds that anyone can measure the strength of a scientific theory by fairly testing its predictions. Scientific research papers, therefore, contain not just the results of an investigation, but all the information needed to replicate the research. Many scientists make their life's work out of replicating the experiments of others in order to test their conclusions.

The third assumption is that individuals and groups can make progress towards understanding natural phenomena, and their discoveries can be replicated at any later time and suitable place by an objective observer. "Truth" in science knows no cultural or national boundaries. Science is not a system of beliefs or faith, but a replicable body of knowledge. In fact, science is incapable of answering questions that are based on faith. That is not to say that within the scientific community, individuals or groups may sometimes see only what they desire to see or have been conditioned to see. Scientific progress is sometimes stalled by incorrect theories or results, but once it is shown that the work cannot be confirmed by others, progress resumes in the correct direction.

The scientific method ultimately allows for the formulation of scientific theories. Part of science education is to learn what these theories are, to trace their operation in the world around us. A "theory" in popular language is a collection of related ideas one supposes to be true, but in science a theory is defined by the principles of the scientific method. These principles, in order of precedence, are:

(1) A scientific theory must be logically consistent and lead to testable predictions about the natural world.
(2) The strength of a scientific theory lies solely in the accuracy of those predictions.
(3) Between two scientific theories with accurate predictions about the natural world, the stronger theory leads to the most predictions with the fewest assumptions.

The making and testing of predictions is what distinguishes science from other intellectual disciplines, and emphasizing the accuracy of predictions rather than the cogency of explanations is the key to scientific progress. A large assortment of recorded observations can often be accounted for with explanations that sound good but are nonetheless wrong. Predictions that can be tested and verified, however, provide a sound standard by which a scientific theory can be judged.

The requirement that a scientific theory makes predictions might seem to reject as unscientific any theory that describes the past. However, scientific theories that describe the past (such as those set forth by geologists, paleontologists, etc.) do make predictions as to what will be observed in the future. For example, if the impact of an asteroid caused a mass extinction at the boundary between the Cretaceous and Tertiary periods over 65 million years ago, then the next sample of rock at or below that boundary will show a much greater number of fossils before the impact. Furthermore, the layer of “dust” falling after the impact will show signs of the explosive nature of the impact.

The three principles that define the scientific method cannot be used to determine how the predictions of scientific theory should be tested. Nor can they be used to create new and even stronger theories. Devising ways to test existing theories or thinking up new theories requires creativity as well as knowledge. It is this opportunity to discover through creative experiments that attracts many young people into science careers. As with all endeavors, however, practice, experience, and the opportunity to watch others engaged in similar efforts can be highly beneficial.

Scientific Practice and Ethics

Scientists have the responsibility to report fully and openly the results of their experiments even if those results disagree with their favored hypothesis. They also have the responsibility to report fully and openly the methods of an experiment. For a scientist to hide data, arbitrarily eliminate outliers in a data set, or conceal how an experiment was conducted is to invite errors and make those errors difficult to discover. All scientists must seek explanations for anomalous observations and results in order to improve their procedures or to discover something new. They also carefully consider questions raised by fellow scientists about the accuracy of their experiments. These accepted ethical practices of scientists also should be taught in the K-12 classroom.

Students sometimes feel pressure to come up with the right or expected answer when performing an investigation. Some may even alter the results of an experiment because they assume an error has been made in observing, measuring, or recording data. Teachers should encourage students to report the results they actually get. Variations in students' results provide opportunities to teach students how to find problems with a procedure or an apparatus. It is as important for students to learn that such problems come with doing science, and to learn how to detect and correct these problems, as it is to reach the nominal goal of an investigation. To discard the unusual in order to reach the expected is to guarantee that nothing but what is expected will ever be seen. This is a distortion of science.

Science and Technology

Technology is the repeatable and controlled manipulation of the natural world to serve human ends. A deep understanding of a phenomenon is not necessary for a successful technology. For example, the Romans did not understand why mixtures of limestone powder, clay, sand, and water hardened, but they had no trouble using the result to mortar bricks. Still, the most spectacular technological advances often have followed from an understanding of fundamental scientific principles. Ancient peoples, for example, used the principles of genetic heredity to improve a few characteristics of some crops and animals, but it was not until the experiments of Gregor Mendel on garden peas in the mid-1800s that the patterns of heredity were revealed. This marked the birth of genetic science, which has led to today's high-yield agricultural technologies and a new era in medicine. As for the ability of the Romans and other earlier civilizations to combine and utilize raw materials, it was only after scientists had sufficient knowledge of physics and chemistry to take those raw materials apart and rebuild them on a molecule-by-molecule or even an atom-by-atom basis that the stuff of today's technologies — from semiconductors and superconductors to a bewilderingly diverse array of synthetics — came into being.

As we learn new scientific principles, we can devise new technologies and expand the use of existing technologies. We cannot predict what new technologies will be available to us even in the next decade, but we can be sure new technologies will be needed to cope with foreseeable problems, such as human population growth, environmental pollution, and finite energy resources. We can also be sure that technological advances will be needed for the problems that no one has foreseen.

Science and Society

Science does not take place in a secret place isolated from the rest of society. Nor are the technologies that it creates exempt from public scrutiny. The continued expansion of scientific knowledge and the new technologies to which that expanded knowledge may lead will inevitably challenge citizens to rethink their ideas and beliefs. For example, as new genetically modified crops and livestock are generated by scientists, some people in the world have expressed concern about safety and ethics. On the other hand, people in developing countries have a compelling interest to use the new technologies to rid themselves of famine and diseases. These types of tradeoffs are likely to become the focus of intense public discussion and political debate.

Within the K-12 classroom, the presentation of some scientific findings or practices may be troubling to students who genuinely feel that those findings or practices conflict with their religious or philosophical beliefs. Dealing constructively and respectfully with these beliefs, while holding firm to the nature of science, is one of the greatest challenges to public school teachers.

Scientifically literate students need to understand clearly the major scientific theories and the principles behind the scientific method. They must also understand that as powerful a process as the scientific method is for predicting natural phenomena, it cannot be used to answer moral and aesthetic questions. Nor can it be used to test hypotheses based on supernatural intervention. Science exclusively concerns itself with predicting the occurrence and consequences of natural events. This is handled explicitly in the Grade 7 of the History-Social Science Content Standards for California Public Schools, where students "analyze the historical developments of the Scientific Revolution and its lasting effect on religious, political and cultural institutions...." The students go on to consider this analysis in terms of the roots of the scientific revolution, the significance of new scientific theories, and the influence of new scientific rationalism on the growth of democratic ideas and the coexistence of science with traditional religious beliefs.

Teaching the Nature of Science and Technology

As students learn the skills and knowledge called for in the Science Content Standards for California Public Schools they will come to know the nature of science implicitly. They will understand the key concepts, principles and theories of science, and they will have practiced scientific inquiry. The guidance and information provided in this framework can be used to implement effective science education programs in K-12 public schools that will provide students with the opportunity to become scientifically literate and understand the nature of science and technology.

There is an increasing number of electronic resources for science education. The California Learning Resource Network (CLRN) (www.clrn.org/science) provides an information source that enables educators to identify supplemental electronic learning resources, including approved Internet sites, that both meet local instructional needs and are aligned with the Science Content Standards for California Public Schools and this Framework. Also, district policy should be followed when using Internet resources.

The presentation of science and technology can often be enriched if it is discussed in the context of history and historical figures. The History-Social Science Content Standards for California Public Schools contain many such examples, including references to scientists such as Franklin, Pasteur, Carver, Curie, Einstein, Copernicus, Galileo, Kepler, and Newton. Inventors such as Edison, Bell, the Wright brothers, Watt, Whitney, and Bessemer are also covered, as is an analysis of the effects of the information and computer revolutions, changes in communication, advances in medicine, and improvements in agricultural technology.